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ECONOMIC OPTIMISATION OF ROBOTIZED MANUFACTURING SYSTEM STRUCTURE FOR MACHINING OF CASING COMPONENTS FOR ELECTRIC MICROMACHINES

The paper presents the optimisation method, with the use of the apparatus of mass service theory, of the number of CNC machine tools in a robotized manufacturing system that can be served by a single robot-manipulator. Calculations were performed for the technology of casing components machining for electric micromachines. The selected optimisation criterion was financial outlays.

Keywords: *structure optimisation; robotized manufacturing; casing components; electric micromachine.*

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ЕКОНОМІЧНА ОПТИМІЗАЦІЯ СТРУКТУРИ РОБОТИЗОВАНОЇ ВИРОБНИЧОЇ СИСТЕМИ ДЛЯ ОБРОБКИ КОРПУСНИХ ДЕТАЛЕЙ ЕЛЕКТРИЧНИХ МІКРОМАШИН

У статті представлено методику оптимізації на основі теорії масового обслуговування кількості верстатів з числовим управлінням у роботизованій виробничій системі, які може обслуговувати один робот-маніпулятор. Обчислення проведено для технології механічної обробки корпусних деталей електричних мікромашин. За критерій оптимізації обрано витрачені кошти.

Ключові слова: *оптимізація структури; роботизоване виробництво; корпусні деталі; електрична мікромашина.*

Форм. 14. Рис. 2. Табл. 2. Літ. 13.

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ЭКОНОМИЧЕСКАЯ ОПТИМИЗАЦИЯ СТРУКТУРЫ РОБОТИЗИРОВАННОЙ СИСТЕМЫ ДЛЯ ОБРАБОТКИ КОРПУСНЫХ ДЕТАЛЕЙ ЭЛЕКТРИЧЕСКИХ МИКРОМАШИН

В статье представлена методика оптимизации на основе теории массового обслуживания количества станков с числовым программным управлением в роботизированной производственной системе, которые может обслуживать один робот-манипулятор. Расчеты выполнены для механической обработки корпусных деталей электрических микромашин. В качестве критерия оптимизации выбраны денежные затраты.

Ключевые слова: *оптимизация структуры; роботизированное производство; корпусные детали; электрическая микромашина.*

Introduction. Ensuring economically effective operation of robotized manufacturing systems is an extremely important problem (Relich et al., 2015; Osak-Sidoruk et al., 2014). It can be achieved, among other things, through the optimisation of work time of machine tools and loading equipment (Anglani et al., 2000; Gola et al., 2015).

An example of such an approach is presented in this paper. Calculations performed were based on the mass service theory as an example of casing components machining for electric micromachines.

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The calculations proposed help determine the optimum number of machine tools served by a single manipulator, with the optimisation criterion being the cost of manufacturing parts in a system (Swic and Taranienko, 2003).

The calculations were based on the following assumptions: m – the number of CNC machine tools; n – the number of robots-manipulators; $\bar{t}_{op}$ – mean operation time of machining a part; λ – mean stream of orders for service; $\bar{t}_{ob}$ – mean service time; μ – density of service stream; P_0 – probability that the robot is not working (waits); $\bar{K}$ – mean number of machine tools on loading; $\bar{S}$ – mean number of machines tools waiting for loading; P_{prz} – probability of a machine tool being idle; tprz – mean idle time of a machine tool; t_{ocz} – mean time of machine tool waiting for loading; $P(n,m)$ – Poisson distribution; $R(n,m)$ – distribution related with Poisson distribution:

$$R(n,m)=\sum_{k=0}^{n}\frac{k^k}{k!}e^{-m}; \quad (1)$$

$$B(m,n,p)=C_m^k p^k q^{m-k}; \quad (2)$$

$$\tilde{B}(m,n,p)=\sum_{l=0}^{k}C_m^l p^l q^{m-l}; \quad (3)$$

$$\lambda=\frac{1}{\bar{t}_{op}}; \quad (4)$$

$$\mu=\frac{1}{\bar{t}_{ob}}; \quad (5)$$

$$\alpha=\frac{\lambda}{\mu}; \quad (6)$$

$$\aleph=\frac{n\times\mu}{\lambda}; \quad (7)$$

$$p=\frac{\alpha}{1+\alpha}. \quad (8)$$

A graph of the states of a manufacturing system composed of 4 machine tools is presented in Figure 1, where: X1 – machine works and does not need loading; X2 – machine completed machining cycle; X3 – machine waits for robot; X4 – machine is served (loading).

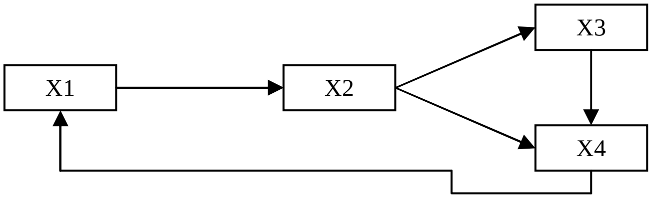


Figure 1. **Graph of system's states,** *authors'*

According to the data from the company under analysis, the maximum time of robot work at loading is $\bar{t}_{ob}$ = 0.4 min and mean operation time $\bar{t}_{ob}$ = 1.33 min. The data were used for the calculation of the parameters of mass service system which, for the case analysed, are presented in Table 1.

Table 1. **Parameters of mass service system,** *authors'*

# of machine tools	# of robots	Parameters					
		Basic			Derivative		
		λ	μ	α	$\aleph$	ρ	q
2	1	0.75	2.5	0.3	3.3	0.23	0.77

Determination of system characteristics was carried out in accordance with the relation recommended in (Terkaj et al., 2010; Kozniewska and Wlodarczyk, 1978), using also (Katz et al., 2002; Swic and Mazurek, 2011; Swic et al., 2014).

Probability that the robot is idle

$$P_0 = \frac{q^m}{\tilde{B}(m,n,p) + \frac{P(n,m)\times R(m-n-1,\kappa)}{P(a,n)\times P(m,\kappa)} q^m}. \quad (9)$$

Mean number of machine tools being loaded

$$\bar{K} = \frac{P_0}{q^m}\sum_{k=0}^{n} k\times B(m,n,p) + \frac{n\times P_0\times P(n,n)R(m-n-1,\kappa)}{P(O,n)\times P(m,\kappa)}. \quad (10)$$

Mean number of machine tools waiting for loading

$$\bar{S} = \frac{P(n,n)\times P_0}{P(o,n)\times P(m,\kappa)}\left[(m-n)R(m-n,\kappa) - \kappa\times R(m-n-1,\kappa)\right]. \quad (11)$$

Mean idle time of machine tool

$$\bar{t}^{ob}_{prz} = \frac{1}{\lambda}\frac{\frac{\bar{S}+\bar{K}}{m}}{1-\frac{\bar{S}+\bar{K}}{m}}. \quad (12)$$

Mean idle time of robot

$$\bar{t}^{r}_{prz} = \frac{1}{\mu}\times\frac{1-\frac{\bar{K}}{n}}{\frac{\bar{K}}{n}}. \quad (13)$$

Mean machine tool waiting time in queue for loading

$$\bar{t}_{ocz} = t^{o}_{prz}\times\frac{1}{\mu}. \quad (14)$$

To simplify further calculations, the following values were selected from (Asl and Ulsoy, 2003; Kozniewska and Wlodarczyk, 1978) in accordance with relations (9)–(11): $P(0;1) = 0.3679$; $R(0;3.3) = 0.0404$; $P(1;1) = 0.3679$; $R(1;3.3) = 0.1671$; $P(2;3.3) = 0.2012$; $R(2;3.3) = 0.3717$.

At $m = 1$ and $n = 2$ the mean idle time of a machine tool at a single loading is $\bar{t}^{o}_{prz} = \bar{t}_{ob}$ = 0.4 min. The mean idle time of the robot while waiting for work equals $\bar{t}^{r}_{prz} = \bar{t}_{ob}$ = 1.33 min. The mean time of a machine tool waiting in queue is $\bar{t}_{ocz}$ = 0 min.

At $m = 2$ and $n = 1$ the following values were obtained: $P_0 = 0.6787$; $\bar{K} = 0.5418$; $\bar{S} = 0.1140$; $\bar{t}^{o}_{prz} = 0.6558$; $\bar{t}^{r}_{prz} = 0.3383$; $\bar{t}_{ocz} = 0.2505$.

The results of the calculations are presented in Table 2.

Table 2. **Economic indices of manufacturing system operation,** *min, authors'*

Characteristics	m = 1 n = 1	m = 2 n = 1	Increase of machine tool idle time	Increase of robot idle time
Machine tool idle time	0.4	0.65	0.25	0.99
Robot idle time	1.33	0.34		
Waiting for loading	0.0	0.25		
Operation time	1.33	1.58		

Assuming time losses for equipment maintenance and breaks for natural needs at the level of 20%, and two-shift work of equipment, the annual effective work time of a machine tool equals: $T_{op.r.}$ = 4030 (1 – 0.2) = 3224 hours.

Machining cycle at $m = 1$, $n = 1$: $t_{c.1}$ = 1.33 + 0.4 = 1.73 min.

Machining cycle at $m = 2$, $n = 1$: $t_{c.2}$ = 1.33 + 0.4 + 0.25 = 1.98 min.

With two-shift work a machine tool can make the following number of components:

$$N_1 = \frac{3224 \times 60}{1.73} = 111815 \text{ pcs}; \quad N_2 = \frac{3224 \times 60}{1.98} = 97697 \text{ pcs}.$$

Therefore, 14118 (difference) parts will have to be manufactured on the second machine tool. For that purpose, at cycle length of 1.73 min we need K machine tools:

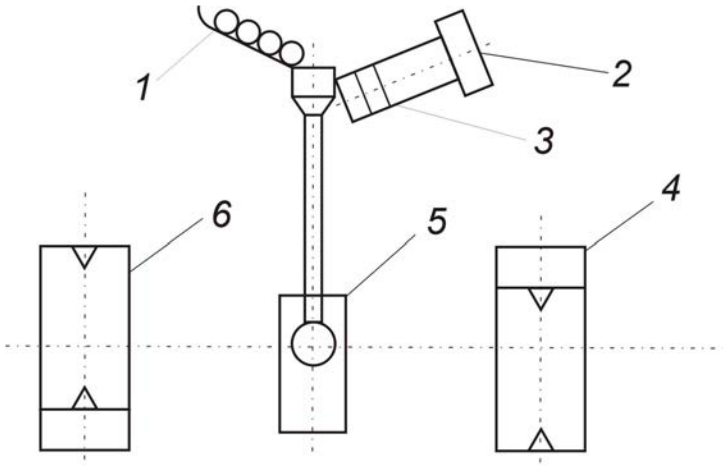
$$K = \frac{1.73 \times 14118}{60 \times 3224} = 0.126 \text{ pcs}.$$

At a CNC machine tool value of the order of 75,000 PLN and at the depreciation rate of 15% the additional outlays on equipment purchase amount to around 11250 PLN, which is comparable with the value of a type "Brig-10B" robot.

Based on the above calculations it can be concluded that in the conditions of casings machining for electric micromachines, at such an operation labour demand, it is justified to use the systems composed of a single CNC machine tool and one robot serving it.

A schematic variant of a robotized manufacturing system setup in which a robot serves two machine tools performing identical operations is presented in Figure 2.

The design features of casing components determine uneven distribution of machining time when turning the LH and RH elements of the components. In the case of various type-size series of the casings the time of machining of the RH side (first operation) is 1.5–2 min, while that of the LH side (second operation) is 0.7–0.9 min (Kozniewska and Wlodarczyk, 1978; Swic et al., 2014). These determinants reduce the efficiency of machines. To increase the index of the machine tools use it is beneficial to arrange the machine tool group according to the scheme "2 machines on the long operation, 1 machine tool on the short one". For the realization of such a scheme the variant presented in Figure 2 was applied.



1 – loading chute – store; 2 – container for machined components; 3 – feeder chute; 4, 6 – semi-automatic cycle machines (1A314C); 5 – robot Brig-10B.

Figure 2. **Setup of manufacturing system for machining casings of electric micromachines** (Swic and Taranienko, 2003)

The most effective method for synthesis of the schematic of control system of a robotized manufacturing system is the method based on logical analysis of the cycle graph of the manufacturing system operation. The basis for the construction of a cycle graph is the sequence of the elements work in the system, generating execution and control commands.

Conclusions. The study presented here confirmed that economically effective operation of a robotized manufacturing system for the machining of components under analysis is possible under the optimum planning of working time for machine tools and loading equipment.

The calculations performed here show that in the case of casings machining for electric micromachines (at the presented operation labour demand) it is expedient to use robotized manufacturing systems composed of one CNC machine tool and one robot serving it.

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Стаття надійшла до редакції 21.07.2015.